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Title: HEAT EXCHANGER AND RELATED EXCHANGE MODULE

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D E C L A R A T I O N

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Dated this July 4, 2006

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DESCRIPTION

"Heat exchanger and related exchange module"

This invention relates to a heat exchanger and a heat exchange module intended to form part of such an exchanger.

A heat exchanger is known from WO 98/16786 in which modules define a first path for a first fluid, each one comprising two metal sheets defining between them a network of channels arranged mutually in parallel from the fluidic point of view. Each channel interposed between two neighbouring channels of the network is, over the whole of its developed length, adjacent to these two neighbouring channels, from which it is isolated by two respective weld lines joining the two metal sheets. A second path for a second fluid is defined between the modules, in the internal volume of a casing enclosing the modules.

According to this document, the modules are manufactured from two flat sheets, which are joined together by weld lines comprising the above-mentioned lines isolating the neighbouring channels from each other, then a pressurised liquid is introduced between the metal sheets, producing an inflation of the two metal sheets between the weld lines, thereby to form the channels. The channels of a same module are in parallel from a fluidic point of view between two distribution zones common to all the channels of a same module, themselves connected to connecting boxes.

During the hydroforming step, i.e. the above-mentioned inflation step, the inflation in the distribution zones is limited so that when in operation the second fluid more easily enters into pseudo-channels formed between the neighbouring modules in the troughs between the successive inflated zones. Apart from these zones of limited inflation, the profile of the channels is continuous and even uniform. Thus the fluid passage cross-sections are only modified locally at the inlet and outlet. The transition between the modified passage cross-section zone and the zone with a constant passage cross-section along the channels, is abrupt and localised.

WO 01/07 854 describes an improvement according to which the channels are U-shaped instead of rectilinear. In a variant illustrated in Figure 25 of this document, a localised

modification is shown of the passage cross-sections with an abrupt transition between the "normal" zone and the modified zone acting as the inlet and outlet of the first and second fluid in the first and second path, respectively.

DE-A1-19639115 describes a heat transfer element in the form of a plate constituted by two metal sheets defining between them channels for an exchange fluid. In embodiments described with reference to Figures 4 and 5, each channel has a general U-shaped configuration which is bifurcated two times successively, such that the passage cross-section varies progressively in a ratio of 1 to 4 from one end to the other of the branched channel. Each channel thus folded back on itself and branched, occupies a rectangular space; the rectangular spaces being contiguous to each other by their adjacent lengths. The purpose of this arrangement is to reduce the speed of the internal fluid when it has almost completed its exchange process, for improved calorific exchange in the zones where the two exchange fluids exhibit a small temperature difference between them. The application indicated is a cooling element for high-temperature batteries for electric vehicles.

Such an exchanger is particularly complex to produce and its flow rate is very limited.

The object of this invention is to propose a heat exchanger which without significant extra expense allows the progress of the flow rates of at least one of the exchange fluids to be controlled, in particular when this fluid undergoes at least a partial change of state, for example condensation, while flowing.

Another object of the invention is to produce a heat exchanger with low pressure losses distributed in a controlled manner.

Another object of the invention is to propose a heat exchange module which can be part of such an exchanger.

According to the invention, the heat exchanger in which modules define a first path for a first fluid and each module comprises two metal sheets forming between them a network of channels which are in parallel with each other from the fluidic point of view, wherein each channel which is interposed between

two neighbouring channels of the network is, over the whole of its developed length, adjacent to these two neighbouring channels and is separated therefrom by two respective weld lines joining the two metal sheets, and a second path for a second fluid is defined between the modules, is characterised by an overall variation in passage cross-section along at least one of the paths, with the channels having continuity of profile.

It has been found according to the invention that a structure of the type described in WO 98/16 786 or WO 01/07 854, i.e. with channels isolated from each other which are adjacent over their whole developed length, is particularly suitable for implementation of overall variations in passage cross-section along at least one of the paths.

By "overall" variation is understood a variation other than the localised path-end variations described above in relation to the prior art, and other than the local variations due for example to the fact that the second exchange fluid, if circulating transversally to the channels, experiences for example a reduction in passage cross-section each time it passes an inflated part of one of the two adjacent modules.

By "continuity of profile of the channels" is indicated that the variations in passage cross-section are not due to profile discontinuities such as cross-sectional variations due to abrupt widening or narrowing, variations due to bifurcation of a single channel into two channels.

The overall variations in cross-section may be obtained according to the invention by channels of different hydraulic diameters, by channels the hydraulic diameter of which varies progressively from one end to the other, and/or by a relative arrangement of the modules which varies the hydraulic diameter between the modules for the second fluid and/or etc.

The hydraulic diameter of a passage for a fluid is the diameter of a theoretical cylindrical tube offering the same flow resistance as the passage in question having a profile other than a circular cylinder.

According to a second aspect of the invention, the heat exchange module comprising two metal sheets forming between them a network of channels with continuous profile arranged in

parallel to each other from a fluidic point of view, each channel interposed between two neighbouring channels of the network being adjacent over the whole of its developed length to these two neighbouring channels from which it is isolated respectively by two weld lines joining the two metal sheets; is characterised by an overall variation in the passage section defined by these channels with continuity of profile of the channels.

Other features and advantages of the invention will become apparent in the following description, which relates to non-limitative examples.

In the attached drawings:

- Figure 1 is a perspective view, with a cut-out, of a vertical-flow parallel current plate heat exchanger;
- Figure 2 is a perspective view of a cross-current plate heat exchanger, the flow in the modules - or plates - being vertical;
- Figure 3 is a perspective view of a plate condenser with the plates arranged in vertical planes and rising gas flow.
- Figure 4 diagrammatically illustrates, two modules according to a first embodiment of the invention, in a perspective view.
- Figures 5 to 8 are views similar to a portion of Figure 4 but illustrating four other embodiments of the invention;
- Figure 9 is a diagrammatic sectional view of a heat exchanger module according to yet another embodiment, during the course of its manufacture by hydroforming in a die;
- Figure 10 is a view of a variant in order to produce a half-die;
- Figure 11 is a perspective view of a heat exchange module according to yet another embodiment;
- Figures 12 and 13 are elevational views of two embodiments for a bundle of modules according to Figure 11;
- Figure 14 diagrammatically illustrates a perspective view of a bundle obtained with modules according to a modification of Figure 11; and

- Figure 15 is a view of another embodiment of a bundle of modules for a heat exchanger according to the invention.

Generally, in the interests of clarity, all the drawings of this application are very diagrammatic, the number of channels in a module being markedly lower than would be found in most real situations, and the metal sheet thickness is represented as unduly large.

Figures 1 to 3 very diagrammatically show different types of heat exchangers by way of illustration, to enable a better understanding of the invention.

In the example shown in Figure 1, the heat exchanger comprises a casing 1 with a rectangular profile with respect to the vertical axis, containing a stack of heat exchange modules 2 in the general form of plates, extending along vertical planes. Each module 2 is essentially made up of two metal sheets 3, which are welded together along vertical weld lines 4, and which are inflated between these weld lines 4 to define between them the vertical channels 6.

Each channel extends with a continuous profile over the whole height of the module 2. All the channels 6 open at each upper and respective lower end, into an upper connection chamber 7 defined in an upper connecting box 8 or respectively in a lower connection chamber 9 defined in a lower connecting box 11. Thus the channels 6 together constitute a first exchange path for a first fluid and this first exchange path may, in operation, be connected by the connecting boxes 8 and 11 to an external circuit for this first fluid. The sealed connection of the channels 6 to the chambers 7 and 9 is provided by bars 12 of a suitable shape which are inserted between the ends of the modules 2 and together form a base for the connecting box 8 or 11 respectively. The channels 6 are thus in parallel from a fluidic point of view with each other between the two connection chambers 7 and 9. Each channel 6 apart from the two end channels of the network of channels of each module is adjacent over its whole developed length to two neighbouring channels, while being isolated from these two neighbouring channels by a respective weld line 4 which is continuous over the whole developed length of the channel. In the case illustrated here where the channels

are rectilinear, the developed length is the same as the overall length. In other cases where the channels are curved and for example have a U-shape as in WO 0107854, the developed length is of course very different to the bulk length.

A second path for a second exchange fluid is defined between the modules 2. The inlet and the outlet in this second path are by means of second connecting boxes 13 and 14 located on the side wall of the casing 1 to enable their internal chambers 16 and 17 respectively to communicate with the gaps 18 between the edges of modules 2, on the side of the ends 19 of the bars 12 which faces away from the connection chamber 7 or 9. In the example of the connecting box 13, its periphery is leak-tightly welded to periphery 22 of a rectangular opening formed in casing 1. One side 21 of the periphery 22 is formed by the aligned ends 19.

Thus a second exchange fluid flows between the connecting boxes 13 and 14, passing through a second exchange path constituted by the internal space of casing 1 located between modules 2.

In the example shown, the lateral connecting box 13 is located in the upper part close to the upper connecting box 8 for the first path, while the lateral connecting box 14 is located on the lower part of casing 1 close to the lower connecting box 11 of the first path. The second fluid enters laterally between the modules, flows between the modules parallel to the channels 6, then exits laterally by the other connecting box. Each of these two fluids may flow upwards or downwards according to the application. The name "counter-current exchanger" describes an exchanger with parallel currents in which the two fluids flow in opposite directions, one upwards and the other downwards in this example. The name "co-current exchanger" describes an exchanger in which the two fluids flow not only parallel, but also in the same direction.

The example shown in Figure 2 will only be described in so far as it differs from that shown in Figure 1.

In this example, the lateral connecting boxes for the second path 13 and 14 completely cover two opposite sides of the casing 1; these sides then being entirely open such that the

second fluid flows in a horizontal direction parallel to the planes of modules 2. Such an exchanger where the two fluids flow in different directions is known as a "cross-current" exchanger.

The example in Figure 3 will only be described in so far as it differs from that shown in Figure 2. In this cross-current exchanger, the channels 6 are oriented horizontally; the modules 2 still being in vertical planes. The path of the first fluid is therefore directed horizontally. In contrast, the connecting boxes for the second fluid 13 and 14 are placed under and over the case 1 such that the direction of flow of the second fluid is vertical between the modules 2. In the example more particularly shown in Figure 3, this concerns a condenser. The lower connecting box 13 comprises an inlet 23 for a gas and the upper connecting box 4 comprises an outlet 24 for the residual gas part from the inlet flow 23. When this flow 23 passes between the modules 2, the channels 6 of which have cooling fluid such as, for example, cold water, passing through them, the condensable part of the second fluid forms droplets which fall back into a bottom 26 of the connecting box 13 and are then evacuated through a lower outlet for liquid 27.

In such a condenser, the second fluid has a volume flow rate which decreases from the inlet 23 to the outlet 24, as the initial volume of gas decreases to the extent that a part of the gas condenses.

Consequently, if the passage cross-section of the second path is approximately the same for the whole length of this second path between the inlet connecting box 13 and the outlet connecting box 14, the speed of flow will decrease. If this is an appropriate speed at the inlet of the second path, it will be too slow for effective exchange near the outlet. If, on the other hand, the speed is appropriate in the region of the outlet, it will be too high at the inlet and the gas will have a tendency to carry droplets along with it towards the outlet, contrary to the separation effect sought.

This example of a condenser has been chosen to clearly demonstrate the advantages of a different passage cross-section in different zones of the same path, but other examples can be envisaged, in particular in an evaporator, or also to adapt the

speeds in the meaning of an optimisation of the result obtained, in particular in terms of heat exchanges.

In the example shown in Figure 4, each module 102 comprises channels 6_a, 6_b, 6_c, 6_d, having different hydraulic diameters.

In the example of Figure 4, the pitch of the weld lines 4, ~~i.e. the distance between the successive weld lines 4 is equal~~ to a constant called P_o. The difference in hydraulic diameter between neighbouring channels is obtained by a difference in inflation of the metal sheets 3 in each zone defining a channel; channels 6_a to 6_d having inflation amplitudes G_a to G_d respectively, which increase from one edge to the other of the module 102. The profile and consequently the hydraulic diameter of each channel 6_a, 6_b, 6_c or 6_d are constant over the whole length of this channel.

When two modules 102 as described are placed side-by-side in parallel planes P, with the modules of the same hydraulic diameter placed facing each other, the available hydraulic diameter in the second path 28 between these modules 102 in a direction perpendicular to that of channels 6_a to 6_d varies overall from one end to the other of the second path. If for example the second path is ascending, in the configuration shown where the channels have a hydraulic diameter increasing from bottom to top, the hydraulic diameter of the second path decreases from its beginning to its end. This corresponds to the desired characteristics in the condenser in Figure 3 according to the explanations given above.

In the example shown in Figure 5, which will only be described with respect to its differences in relation to the example in Figure 4, each module 202 comprises groups of channels having identical hydraulic diameters; however these diameters being different from one group to another. In the diagrammatic representation of Figure 5, there are two groups each of two channels, namely the lower group of channels 6_a, 6_b with an identical relatively small hydraulic diameter, and the upper group of channels 6_c and 6_d with an identical relatively large hydraulic diameter. Here once again, the differences in diameter are the result of different levels of inflation with an identical pitch P_o. Consequently, the second path 28 comprises a

first hydraulic diameter between the channels 6_a and 6_b of the neighbouring modules 202, and a second smaller hydraulic diameter between the neighbouring channels 6_c and 6_d.

In the example in Figure 6, which will only be described with respect to its differences in relation to the example in Figure 5, between the two groups of channels 6_a, 6_b and 6_c, 6_d there is an intermediate channel 6_e with an inflation of G_e which has an intermediate value between the lower value of channels 6_a and 6_b and the higher value of channels 6_c and 6_d. Consequently, the hydraulic diameter 6_e is intermediate between that of channels 6_a and 6_b, and the larger value of channels 6_c and 6_d. Furthermore, the second path 28 has between the channels 6_e of the neighbouring modules 302, an intermediate value between the larger one defined between the channels 6_a and 6_b and the smaller one defined between the channels 6_c and 6_d.

In all the examples described up to this point the pitch P_o between the weld lines 4 was the same for all the weld lines for one module and for all of the modules. In the example shown in Figure 7, the inflations G_o are the same for all the channels of all the modules 402. In contrast, the channels of a network comprise a first group of channels 6_g and a second group of channels 6_h. The pitch P_g between two weld lines defining between them a channel 6_g is greater than the pitch P_h between two weld lines defining between them a channel 6_h. In this example, the hydraulic diameter of the path 28 decreases when the pitch of the weld lines decreases.

The example shown in Figure 8 combines the pitch and inflation variations. There are four channels 6_j, 6_k, 6_m, 6_n with pitches P_j to P_n which increase regularly and inflations G_j to G_n which also increase regularly from bottom to top of each module 502.

Figure 9 illustrates the hydroforming stage to produce a module with four groups of channels 6_p, 6_q 6_r 6_s, having different hydraulic diameters resulting at least in part from different levels of inflation. Before injection of the hydroforming liquid, the flat blank of the module, comprising at this stage two flat metal sheets welded together, for example by laser welding, along the weld lines such as 4 in the previous figures,

between dies 31, 32 which between them define a cavity with working surfaces 33_p, 33_q, 33_r, 33_s, and 34_p, 34_q, 34_r, 34_s respectively, between which the module blank is laid and which have between each pair of surfaces, a distance corresponding to the required inflation in each area respectively. Figure 9 shows the result obtained after differentiated inflation of the different channels following separation of the working surfaces between which they are located.

Figure 10 illustrates less expensive tooling in which each die (only the lower die 31 is shown) has a flat working surface 33 corresponding to the maximum inflation envisaged, and separate shims 36_p, 36_q, 36_s to define the zones where less inflation is required.

For the upper die 32 (not shown in Figure 10), the shims should be fixed below the working surface of the die to avoid them moving by gravity before the hydroforming stage. For the lower die, it is also desirable for the shims to be fixed.

Figures 9 and 10 also illustrate that the invention enables the hydraulic diameters to be varied in a first direction, for example in the direction of increase, for example between the groups 6_p and 6_q or 6_q and 6_r, then in a second direction, here the direction of decrease between the group 6_r and 6_s, when this is required to optimise the exchanger.

In all the examples described with reference to Figures 4 to 8, the weld lines 4 of a module are mutually parallel and the hydraulic diameter of a channel is constant over its whole length.

In the example represented in Figure 11, the weld lines 604 of a module 602 are all convergent; in this example towards a single point situated beyond one of the ends of the module. In other words, the neighbouring weld lines between them form a relatively narrow angle, labelled as A in Figure 11. Thus, the pitch between successive weld lines increases from one end to the other of each channel, as does the hydraulic diameter of the channel. Such a module has an isosceles trapezoidal general shape, with oblique longitudinal sides 37 which are approximately parallel to the two outside weld lines 604 of the network of channels.

Such a module is useful in order to produce a condenser in a configuration according to Figure 1 or Figure 2; i.e. with vertical channels. If the large end of the channels is facing upwards, the fluid to be condensed may follow a descending path within the channels where it encounters a hydraulic diameter which decreases in relation to the reduction in volume of the fluid by condensation. The second fluid, for example water, passes between the modules, or may form a bath between the modules. With the same arrangement of modules, an ascending-flow evaporator can also be produced; the first fluid encountering increasing hydraulic diameters as its volume increases due to evaporation.

Such a module can also be arranged with the large end of the channels downwards in order to produce, for example, a reflux condenser; i.e. as described above with reference to Figure 3, with an increasing evaporation flow and droplets forming which flow back to the base and into a collector.

The inflation of the channels may be constant along each channel, or alternatively may increase from the narrower end to the wider end of each channel.

Figure 12 shows an elevation view of a bundle of modules 602 with channels where the inflation increases from bottom to top and where the modules are in parallel vertical planes. In the example shown in Figure 13, modules 602 identical to those in Figure 12 are placed in planes which converge towards a point located above the narrow end of the channels so as to reduce the hydraulic diameter of the second path on the side where the ends of the channels are narrow, in relation to the embodiment in Figure 12.

Figure 14 shows the bundle very diagrammatically when the inflation is constant along each channel of the modules according to Figure 11. The bundle has the shape of a hexahedron in which the two opposite faces are isosceles trapeziums in parallel planes. A casing for such a bundle typically has a corresponding shape, with two opposing parallel faces in the shape of an isosceles trapezium and two rectangular faces joining the oblique sides of the trapeziums.

If, moreover, the inflations of the channels are variable as illustrated in Figures 12 and 13, the bundle takes the general shape of a truncated pyramid, i.e. the two trapezoidal faces are inclined in relation to each other and the two other lateral faces also become trapezoidal. The casing typically has a corresponding shape.

In the example shown in Figure 15, the modules 702 have channels which are all identical with the same widths and the same inflations over the whole of their length. These modules are arranged in a fan-shape in relation to each other, thus in oblique planes with respect to each other, converging beyond one end of the channels such that the hydraulic diameter of the second path, assumed to be for co-current or counter-current, varies from one end to the other.

In a way which is not shown, it is also possible to position the modules in relation to each other in a fan shape by relative pivoting about an axis parallel to the weld lines, thus to the longitudinal direction of the channels, in order to produce a variable hydraulic diameter of the second path when the exchanger is the cross-current type.

In the examples in Figures 1 to 3, the modules 2 are offset in relation to each other in their own plane such that the peaks of undulation of one module are located opposite the troughs of undulation of the two neighbouring modules. This arrangement favours circulation in the second path following a transverse direction to the channels, whether for a cross-current exchanger (Figures 2 and 3) or for the entry of the second fluid by a side opening and the exit of the second fluid by another side opening in the case of a parallel-current exchanger (Figure 1). However, in order to simplify the illustrations, all the examples given with reference to Figures 4 to 8, 14 and 15 represent another possible arrangement, with the undulations of two neighbouring modules facing each other peak-to-peak and trough-to-trough. This is simply by way of illustration, and the invention is equally applicable with an offset arrangement, for example the one in Figures 1 to 3.

The invention is particularly applicable with the following dimensions:

- developed length of channels: 0.5 to 10 m
- width of the network of channels: 0.15 to 2 m
- pitch sequence of modules: 8 to 105 mm
- pitch sequence of weld lines: 10 to 100 mm
- inflation of channels: 5 to 80 mm measured inside the channels.

The metal sheets are typically of stainless steel of a thickness of a few tenths of a millimetre (no upper limit at 10/10) with the understanding that a thin sheet is preferable for thermal exchange but that the pressure differences between the two fluids and the thermal stresses must also be taken into account.

Of course, the invention is not limited to the examples described and represented. The means of varying the hydraulic diameter described may be combined in very many ways.

It is conceivable to produce channels which have a constant hydraulic diameter over one part of their length and a progressively variable hydraulic diameter over another part of their length.

The exchangers described with reference to Figures 1 to 3 are not in any way limitative. For example, if the exchange modules are arranged without offsetting between them, thus with the undulations facing peak-to-peak, it is possible to locally reduce the inflation of the channels in the zones envisaged for the lateral introduction of the second fluid, in a similar manner to that described with reference to Figure 25 of WO 01/07 854. When the second fluid is a bath, the casing may be unnecessary.

The invention is compatible with non-rectilinear channels, for example the U-shaped channels of WO 01/07 854.

With respect to the example in Figures 11 to 14, it is also possible to have modules in which:

- the inflation varies progressively along each channel;
- the pitch between weld lines, on the other hand, is constant.